University of Technology Sydney

Doctoral Thesis

Protection of Macrogrids and Microgrids by Smart Selection of Electrical Quantities

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A thesis submitted in fulfilment of the requirements
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Declaration of Authorship

I, Behnam Mahamedi, declare that the thesis titled "**Protection of Macrogrids and Microgrids by Smart Selection of Electrical Quantities**" is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering, Faculty of Engineering and IT @ University of Technology Sydney. I confirm that:

- This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

- This document has not been submitted for qualifications at any other academic institution.

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"I have no special talent. I am only **passionately** curious."

Albert Einstein

Abstract

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by Smart Selection of Electrical Quantities

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This thesis addresses two nearly separate topics in power systems: macrogrid protection and microgrid protection. These two types of grids differ in some principal electric characteristics that determine how to deal with faults. For example, the ratio between reactance and resistance is far larger in macrogrids than in micrograids. However, the basic principles in protective relaying hold true for both cases, i.e., protection should be reliable, fast, and selective for both macrogrids and microgrids. In this thesis, the concept of smart selection of electrical quantities (EQ) is introduced for the first time to identify faults in both macrogrids and microgrids by using specific EQs instead of immediate electrical signals. Thanks to the advanced technology in digital relays, it is now possible to program protective relays based on the unique features of some EQs whereby fault and non-fault conditions can be discriminated. This way, protection engineers can benefit from the advantages of these methods in terms of more reliable operation and ease of implementation and setting.

At first, this thesis details different elements of fault identification or protective relaying. Then, macrogrid protection is considered in Part I of this thesis. Fault detection, fault polarization, faulted phase selection, and fault location on transmission lines are addressed. Thanks to the smart selection of EQs, the presented methods require less setting or no setting, while the reliable operation is preserved. Since multiple protective schemes already exist in macrogrids, the presented methods in Part I contribute to state-of-the-art technology with an *improvement* to protective relaying in macrogrids.

Part II of this thesis is devoted to microgrid protection, where a reliable protective scheme is yet to come. Firstly, fault characteristics of inverters, an essential part of microgrids to be understood, are analysed, which in turn helps us with inverter models in the sequence domain, an unavoidable concept in protective relaying. Fault polarization is then addressed, as this author believes that a faulted section in *microgrids* can be more reliably identified by a directional comparison scheme than other protective schemes. This, however, depends on the correct outcome of fault direction. Developing the sequence models of inverters, and following the same idea, i.e., smart selection of EQs, the author tackled critical challenges to the protection of microgrids by developing new methods of fault polarization in microgrids. The directional elements developed based on these techniques can cope with the complexities caused by faults in microgrids.

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Abbreviations

CDR	**C**urrent **D**ivision **R**ule
EQ	**E**lectrical **Q**uantity
EPS	**E**lectric **P**ower **S**ystem
FL	**F**ault **L**ocation
OCR	**O**ver-**C**urrent **R**elay
RCS	**R**eliabilty, **C**elerity, **S**electivity
CB	**C**ircuit **B**reaker
IED	**I**ntelligent **E**lectronic **D**evice
AC	**A**lternating **C**urrent
DC	**D**irect **C**urrent
CC	**C**orrelation **C**oefficient
IIDG	**I**nverter-**I**nterfaced **D**istributed **G**enerators
TL	**T**ransmission **L**ine

Symbols

R	Resistance	Ω
X	Reactance	Ω
$\mathbf{Z}$	Impedance Vector	Ω
S	Apparent Power	VA
$\mathbf{S}$	Complex Power	VA
P	Active Power	W
Q	Reactive Power	VAr
$\mathbf{V0}$	Zero-Sequence Voltage	V
$\mathbf{V1}$	Positive-Sequence Voltage	V
$\mathbf{V2}$	Negative-Sequence Voltage	V
$\mathbf{I0}$	Zero-Sequence Current	A
$\mathbf{I1}$	Positive-Sequence Current	A
$\mathbf{I2}$	Negative-Sequence Current	A
$\mathbf{Z0}$	Zero-Sequence Impedance	Ω
$\mathbf{Z1}$	Positive-Sequence Impedance	Ω
$\mathbf{Z2}$	Negative-Sequence Impedance	Ω
$\boldsymbol{\alpha}$	Complex Operator $e^{j2\pi/3}$	—
$\mathbf{g}$	Arbitrary Math Function	—
$\Re\{\}$	Real-value operator	—
$\Im\{\}$	Imaginary-value operator	—
ω	angular frequency	rads^{-1}

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THE LIGHT AND THE CREATOR OF LIGHTS